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[Original articles]

Evaluation of environmental feasibility on steel pipe sheet pile cutoff wall at coastal landfill sites

by

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Makoto Kimura [4] and Masashi Kamon [5]

Abstract:

An evaluation method that can express the local leakage of leachate from joint sections in steel pipe sheet pile (SPSP) cutoff walls is discussed, in this study. In particular, the evaluation of environmental feasibility (containment of leachates containing toxic substances) considering a three-dimensional arrangement and hydraulic conductivity distribution of the joint sections in the SPSP cutoff wall is compared with an evaluation that generally uses the equivalent hydraulic conductivity. This equivalent hydraulic conductivity assumes that the joint section and the steel pipe are integrated; therefore, the hydraulic conductivity is substituted with a uniform permeable layer. However, in an evaluation that employs the equivalent hydraulic conductivity, it is difficult to consider the local leakage of leachate containing toxic substances from the joint sections in the SPSP cutoff wall. This paper concluded that evaluations of the environmental feasibilities of the SPSP cutoff walls with joint sections must take into account the local leakage of leachates containing toxic substances from the joint section. Also, it was clarified that technologies that lower the hydraulic conductivities of joint sections in SPSP cutoff walls and also facilitate the use of sparser arrangements contribute significantly to increasing the environmental feasibilities of SPSP cutoff walls at landfill sites.

Keywords:

Coastal landfill site / Environmental feasibility / Local leakage of leachate / Steel pipe sheet pile / Vertical cutoff barrier

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Introduction

Landfill sites are facilities where the final residue is disposed after all possible recycling energy has been recovered from it. Therefore, landfill sites are an important part of civil infrastructure, required for environmental conservation without dumping waste in residential areas. However, in many cases, the construction of landfill sites has been opposed due to concerns of residents living the vicinity regarding environment safety with regard to situations such as “the leachate from waste may leak out”; hence, the construction of new landfill sites has become more difficult. Moreover, the construction cost of landfill sites has also significantly increased simultaneously due to tighter environmental legislation.[1, 2]

In Japan, small-scale inland landfill sites were often constructed in the river-head areas of mountain valleys. With regard to the abovementioned social concerns regarding the landfill sites, the locations of landfills have recently been diversified into coastal areas on a large scale. These sites are developed at urban harbour areas in order to reduce the risk of contaminating the groundwater, which can be caused by the leakage of leachate, and conserve the water resources.[3] In the national statistics of 2003 announced at Ministry of the Environment, the capacity of coastal landfill sites was 23.3% of that of all landfill sites, and particularly in metropolitan areas, it was greater than 80% (*see* Fig. 1). These statistics indicate that the role of coastal landfill sites has been increasing steadily. However, the residents living in the vicinity of these sites continue to express the same concerns for environment safety. Therefore, ensuring stable and systematic operation of the coastal landfill sites in the future and prolonging the life of coastal landfill sites constructed until now are important matters of concern, particularly in metropolitan areas.

A revetment at a coastal landfill site ensures space for waste disposal and harbour maintenance during the disposal of waste, construction sludge, dredged soil etc. A revetment

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at a coastal landfill site must function as a vertical (side) cutoff barrier that prevents the leakage of leachate containing toxic substances from the landfill waste, into the sea; furthermore revetments must protect the coastal landfill site from various external forces such as earthquakes, ocean waves, high tides and tsunamis.[4]

Recently, steel pipe sheet piles (SPSPs), using which the deepwater construction is possible[5], have been widely employed in vertical cutoff barriers at coastal landfill sites due to their workability and economical efficiency. A vertical cutoff barrier employing SPSPs is called a “SPSP cutoff wall” in this study. However, the design and application of SPSP cutoff walls, evaluation of environmental feasibility, construction technology and long-term maintenance are very complicated both experimentally and analytically.[6] This is because of the existence of joint sections in the SPSPs, as shown in Fig. 2.

The appropriately estimation of the hydraulic performance of SPSPs with joint sections (shown in Fig. 2) is an important issue, particularly in the evaluation of environmental feasibility, that is, the containment of leachates containing toxic substances. Figure 3 shows the characterization of the environmental feasibility of vertical and bottom cutoff barriers as well as the overall landfill site. When evaluating the hydraulic performance of an SPSP cutoff wall, an equivalent hydraulic conductivity is generally obtained.[4] This equivalent hydraulic conductivity assumes that the joint section and the steel pipe are integrated; therefore, the hydraulic conductivity is substituted with a uniform permeable layer (*see* Fig. 4). The Prime Minister’s Office and the Ministry of Health and Welfare says that the integrated equivalent hydraulic conductivity with 50 cm thickness must be 1.0×10^{-6} cm/s or less.[4] However, in an evaluation that employs the equivalent hydraulic conductivity, it is difficult to consider the local leakage of leachate containing toxic substances from the joint sections in the SPSP cutoff wall.

In this study, an evaluation method that can express the local leakage of leachate

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from the joint sections in the SPSP cutoff walls is discussed. In particular, the evaluation of the environmental feasibility (containment of leachates containing toxic substances) considering a three-dimensional arrangement and hydraulic conductivity distribution of the joint sections in the SPSP cutoff wall is compared with an evaluation that uses the equivalent hydraulic conductivity.

Analysis for environmental feasibility

Overview

The development of methods for the detection of the generation points of leachate leakage has been conducted in various different ways at inland and coastal landfill sites in order to determine when the leachate containing toxic substances will leak into the surrounding areas after the land has been reclaimed at the landfill site.[7, 8] However, the present detection methods are insufficient with regard to their durability, and the use of these methods may lead to excess cost and time for repairing the generation points of leachate leakage in the vertical and bottom cutoff barriers at the landfill sites. Therefore, an effective implementation and verification of the seepage and advection/dispersion analysis, considered as a two-dimensional or a three-dimensional problem, of the leaching behavior of leachate containing toxic substances are necessary along with the upgradation of the technique used to repair vertical and bottom cutoff barriers. The structure of vertical and bottom cutoff barriers that can ensure long-term stability as well as the evaluation method for the environmental feasibility of landfill sites must be also discussed.

The leaching behavior of leachates containing toxic substances near the vertical and bottom cutoff barriers at landfill sites must be considered with regard to not only infiltration

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but also the advection and dispersion phenomena[2]. Therefore, these phenomena must be accurately reproduced in the implementation of the seepage and advection/dispersion analysis. In this study, the infiltration, advection and dispersion phenomena must be expressed three-dimensionally in order to account for the joint sections in the SPSP cutoff walls. Also, the analysis of coastal landfill sites, unlike that for inland landfill sites, must consider the effect of tides, etc. Furthermore, each vertical and bottom cutoff barrier is a composite structure consisting of synthetic fiber, steel, rubble and the seabed; this composite structure must be reproduced accurately.

The Eulerian-Lagrangean finite-element method is a numerical calculation method that is known to be useful in efficiently reproducing such complicated phenomena. In this study, the seepage and advection/dispersion analysis is performed using Dtransu-3D/EL, which is used as a representative analysis code.[9]

Objective and assessment index

In an SPSP cutoff wall, joint sections are arranged between steel pipes, forming a three-dimensional structure (*see* Fig. 2). Therefore, it is necessary to accurately reproduce the local leakage of leachates from the joint sections for the evaluation of the environmental feasibility of the SPSP cutoff wall. In this study, the leachate-containment effect of the SPSP cutoff wall is evaluated by using a three-dimensional seepage and advection/dispersion analysis (Dtransu-3D/EL). This analysis reproduces the existence of joint sections more precisely.

Figure 5 shows the three-dimensional cross-section of a landfill site assumed as a basic case in this analysis. The SPSP cutoff wall as well as a part of the composition layer around it in the coastal landfill site is considered for setting the three-dimensional cross-section. At the bottom of the waste layer as well as in the sea bed, a clay deposit layer is

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assumed to exist, and this layer fulfils the role as a bottom cutoff barrier in the coastal landfill site. The SPSP cutoff wall is penetrated upto a depth of 3 m in the clay deposit layer, and the hydraulic conductivity of the SPSP cutoff wall is varied to provide different examination cases.

In the construction of the SPSP cutoff wall at coastal landfill sites, double SPSP cutoff walls may be used due to ensure mechanical stability and fail-safe concept of landfill sites, as shown in the overview in Fig. 6. Furthermore, the clay deposit layer may be improved by sand compaction pile (SCP) methods in order to enhance the mechanical stability of the SPSP cutoff walls.[4] However, the main objective of this study is the evaluation of the environmental feasibility (containment effect of leachate containing toxic substances) of the SPSP cutoff wall. Therefore, the coastal landfill site is simplified, as shown in Fig. 5, as a three-dimensional cross-section that comprises a single SPSP cutoff wall, waste layer and clay deposit layer. The three-dimensional cross-section assumes the extreme conditions for the vertical and bottom cutoff barriers that would pose environmental pollution risks to the surroundings affected by coastal landfill sites.

In coastal landfill sites, the difference in the water level between the inside and outside landfill site is controlled on a daily basis so that it may not exceed 2 m.[4] On the other hand, in the three-dimensional cross-section shown in Fig. 5, a controlled water level regulated to 2 m is reproduced by the boundary conditions, that is, a fixed total head of 0 and 2 m are assigned to the upper sides of the sea area and waste layer, respectively. The boundary edges in the three-dimensional cross-section of the coastal landfill site are assumed to be undrained. The seepage, advection and dispersion properties assigned to each composition layer in this analysis are shown at Table 1. These values shown in Table 1 are typical one for heavy metals and composition layers.[4, 6] This analysis assumes that mechanical properties of each composition layer are not considered.

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Presently, in Japan, waste discharge waste is burnt once at a refuse incinerator plant, and the incinerated residue generated from the incinerator plant is mainly used to reclaim land at landfill sites.[3] Therefore, the type of waste dumped in the recently constructed landfill sites has changed from the conventional organic substances to inorganic substances; thus, the heavy metals which may be contained in the incinerated residue are among the major environmental pollutants. If the leachate leakage occurs at a landfill site into the surrounding areas, the heavy metals also may leak out together with the leachate due to the advection-dispersion phenomenon, as heavy metals are soluble in water. Therefore, this study assumes heavy metals as toxic substances that may leak out from coastal landfill sites. This analysis assumes the waste layer to be a contamination source, and the concentration of toxic substances (heavy metals) at the waste layer is assigned the value of 1 as the initial condition. The initial relative concentration of toxic substances is initialized to 0 in regions outside the waste layer.

As an environmental conservation standard for coastal landfill sites,[8] the environmental standard values (*see* Table 2 (b) and (c)) for water quality and bottom sediment of the sea areas near landfill sites equal 0.1 times that of the acceptable standard values (*see* Table 2(a)) for waste disposed at landfill sites. Therefore, the concentration of toxic substances at the SPSP cutoff wall on the sea side (that is the cross-section delimited by the broken line at Fig. 5) is targeted in this analysis as an important index of the environmental feasibility of SPSP cutoff walls. In this analysis, the elapsed time during which the concentration of toxic substances reaches 0.1 on the sea side of the SPSP cutoff wall is estimated; when this occurs, the SPSP cutoff wall as well as the coastal landfill site is defined as having lost its environmental feasibility.

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SP/JS-model considering local water leakage in joint sections

In the evaluation of the environmental feasibility (containment effect of leachate containing toxic substances) of SPSP cutoff walls at coastal landfill sites, the equivalent hydraulic conductivity is generally used.[4] This method involves calculating the hydraulic conductivity of an SPSP cutoff wall equivalent to a uniform permeable layer of thickness 50 cm (*see* Fig. 4) by considering the steel pipes and joint sections that constitute the SPSP cutoff wall as a single body. Because the equivalent hydraulic conductivity can be directly verified with the technical standards for vertical and bottom cutoff barriers at landfill sites, it is frequently used in the technical development of the SPSP cutoff wall. However, the value equivalent hydraulic conductivity is the average hydraulic conductivity of the joint sections, which have high permeability, and that of the steel pipe sections, which are impermeable. Therefore, an evaluation using the equivalent hydraulic conductivity cannot easily detect the position or the time of leachate leakage, thus making it difficult to estimate the environmental impact of local leakage from the joint sections of the SPSP cutoff wall. Where, development of these detections will contribute strongly for the optimization of maintenance and management in SPSP cutoff wall.

In this study, an evaluation method that can express the local leakage at the joint sections of SPSP cutoff walls is discussed. The evaluation method using the equivalent hydraulic conductivity is defined as the “UL-model”, and the evaluation method that considers the steel pipe and joint sections, that is, the local leachate leakage, is defined as the “SP-JS-model”. Figure 7 shows a general description of the UL-model and SP/JS-model. In the UL-model (shown in Fig. 7(a)), equivalent hydraulic conductivities of 2.0×10^{-6}, 1.0×10^{-6}, 1.0×10^{-7} and 1.0×10^{-8} cm/s were assigned to the entire SPSP cutoff wall. In the SP/JS-model (*see* Fig. 7(b)), the joint sections were placed at 0.25 m intervals for steel pipes of diameter 1 m, which represents the standard sizes of the SPSP shown in Fig. 2. Furthermore, hydraulic

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conductivities were assigned to each steel pipe and joint section in the SP/JS-model such that the entire hydraulic conductivity of the SPSP cutoff wall equals the equivalent hydraulic conductivity assigned in the UL-model, that is, hydraulic conductivities of 2.5×10^{-6}, 1.3×10^{-6}, 1.3×10^{-7} and 1.3×10^{-8} cm/s were assigned to the joint sections, assuming that the hydraulic conductivity of steel pipe is infinitely small. Table 1 shows the seepage, advection and dispersion properties assigned to each composition layer in both the models.

Results and discussion

Environmental feasibility of SPSP cutoff wall considering local water leakage

Figure 8 shows the concentration flux (the material quantity passing through a unit area in unit time) of toxic substances leaking from the SPSP cutoff wall on the sea side. The fluxes in the uniform layer of the UL-model and in each steel pipe and joint section of the SP/JS-model are plotted in Fig. 8. The relationship between the elapsed time and the highest concentration of toxic substances leaked from the SPSP cutoff wall on the sea side for both the models is shown in Fig. 9. Figure 10 illustrates the distribution of the concentration of toxic substances leaking out from the waste layer, which is the contaminated source, for both the models. Figure 10 expresses the distribution of the concentration on the sea side of the SPSP cutoff wall in order to facilitate the comparison of both the models with regard to the leakage of the toxic substance to the surroundings of the coastal landfill site.

In the SP/JS-model, the concentration flux of toxic substances leaked onto the sea side of the SPSP cutoff wall, particularly from the joint sections, is increased as compared to that of the UL-model (*see* Fig. 8). The SP/JS-model can quantitatively express the concentration of toxic substances at the joint sections of the SPSP cutoff wall, where the

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hydraulic conductivity is higher than that in the steel pipe. In the UL-model, as shown in Fig. 10, the leachate leaks uniformly from the SPSP cutoff wall onto the sea side, and this leakage tends to uniformly increase with time. In the SP/JS-model, it being different from the UL-model, the leachate leaks locally from the joint sections onto the sea side of the SPSP cutoff wall, and this leakage increases locally with time at the joint sections (*see* Fig. 10). Consequently, the increase in the concentration of toxic substances leaked from the SPSP cutoff wall onto the sea side is found to occur earlier in the SP/JS-model than in the UL-model, as shown in Fig. 9.

For example, 70 and 110 years, respectively, are required in the SP/JS-model (the hydraulic conductivity of the entire SPSP cutoff wall is 1.0×10^{-8} cm/s) and the UL-model for the concentration of toxic substances in the SPSP cutoff wall on the sea side to reach C=0.1, which is assumed as the assessment index. In the other analyzed conditions under which the hydraulic conductivity of the entire SPSP cutoff wall is equivalent in both models, the leakage of leachate is confirmed to occur earlier in the SP/JS-model than in the UL-model due to effect of the local leakage of leachate (*see* Fig. 11). This tendency becomes more remarkable with increase in the hydraulic conductivity of the entire SPSP cutoff wall (*see* Fig. 12).

Thus, as mentioned above, the reproduction of the local leakage of leachate generated at the joint sections of SPSP cutoff walls is possible by using the SP/JS-model for the evaluation of the environmental feasibility of SPSP cutoff walls at coastal landfill sites. Furthermore, the SP/JS-model indicates that toxic substances in concentrations exceeding the environmental standard values are leaked out of coastal landfill sites earlier than that estimated using the UL-model (*see* Fig. 9). Using the UL-model, the local leakage of leachate containing toxic substances from the SPSP cutoff wall cannot be reproduced, although the total quantity of the toxic substances leaked from the SPSP cutoff wall can be estimated. This provides a safer-side estimate of the environmental feasibility from the viewpoint of the time

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taken for the leakage of toxic substances. In addition, by using the UL-model, it is difficult to quantitatively detect the generation position in the SPSP cutoff wall where the leachate containing toxic substances are leaked. An appropriate estimation in terms of both position and time at which the loss of environmental feasibility occurs is important in order to control and maintain a long-term SPSP cutoff wall at coastal landfill sites. Based on the abovementioned points, the environmental feasibility of SPSP cutoff walls must be verified by using the SP/JS-model.

Environmental feasibility of SPSP Cutoff Wall considering joint sections

Various types of joints are adopted for the joint sections of the SPSP cutoff walls, as shown in Fig. 2. The types of joints for which the hydraulic performance has been reported experimentally are the P-T joints in which the packing mortar is filled in the joint space, the improved P-T joint in which a rubber board is installed with the mortar filling in the joint space and the H-H joint for H-jointed SPSP in which a water-swelling sheet is applied in the joint spaces.[10, 11, 12, 13] Based on past reports, the SPSPs with the P-T joint, improved P-T joint and H-H joint exhibit equivalent hydraulic conductivity levels of 1×10^{-6}, 1×10^{-8} and 1×10^{-9} cm/s, respectively, under specific experimental conditions under which the difference between the water levels inside and outside the landfill site is less than 5 m.[11, 12, 13] However, the reported hydraulic performances of the SPSP cutoff walls with the joint sections has been based on the equivalent hydraulic conductivities obtained from experimental studies.

In this study, the reported equivalent hydraulic conductivities of SPSP cutoff walls are converted to individual hydraulic conductivities in the steel pipe and joint sections. Furthermore, the environmental feasibilities of SPSP cutoff walls with various joints types are evaluated by applying each converted hydraulic conductivity in the SP/JS-model. Figure 13

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shows the equivalent hydraulic conductivities of SPSP cutoff walls with various joints types, the dimension of each joint type as well as steel pipe and the hydraulic conductivity of each joint type. In the evaluation of the environmental feasibilities on SPSP cutoff walls considering various joint geometries and performance levels, the SPSP cutoff walls with the following four joint types are applied to the SP/JS-model.

Case-I: SPSP cutoff wall with the P-T joint

Case-II: SPSP cutoff wall with the improved P-T joint

Case-III: H-jointed SPSP cutoff wall with the improved P-T joint

Case-IV: H-jointed SPSP cutoff wall with the H-H joint

Figure 13 shows also the outline of the SP/JS-model for Case-I to Case-IV. Joint sections of width 0.25 m and steel pipes of diameter 1 m were used in Case-I and Case-II, whereas joint sections of widths 0.25 m and 0.5 m were used in Case-III and Case-IV, respectively, along with H-jointed steel pipes of diameter 2.25 m.[11, 12, 13] Table 1 shows the seepage, advection and dispersion properties assigned to each composition layer. The assumed hydraulic conductivities of the joint sections were 1.3×10^{-6} cm/s in Case-I, 1.3×10^{-8} cm/s in Case-II and Case-III and 1.8×10^{-9}cm/s in Case-IV.

Figure 14 shows the total quantities of toxic substances leaked from the SPSP cutoff wall onto the sea side with respect to the elapsed time for Case-I to Case-IV. The relationships between the elapsed time and the highest concentration of toxic substances leaked from the SPSP cutoff wall onto the sea side for Case-I to Case-IV are shown in Fig. 15. Figure 16 shows the distribution of the concentration of toxic substances leaking out from the waste layer, that is, the contamination source, in Case-I to Case-IV. This distribution in Fig. 16 is expressed from the sea side of the SPSP cutoff wall in order to facilitate a comparison among Case-I to Case-IV with regard to the leakage of the toxic substance to outside the coastal landfill.

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The times required for the concentration levels on the sea side to exceed C=0.1 were less than 1 year and 70 years for Case-I and the Case-II, respectively (*see* Fig. 15). In Case-III and Case-IV, the leakage of toxic substances in excess of environmental standard value (C=0.1) was not confirmed, even for durations upto 140 years. In Case-I and Case-II, the hydraulic conductivities of the joint sections are different, although the arrangement intervals of the joint sections are the same; thus it has been proven that low-hydraulic conductivity joint sections in SPSP cutoff walls significantly contribute toward increasing the leachate-containment effect. In addition, the sparser arrangement of joint sections represented in Case-III reduces the total quantity of toxic substances leaked from the SPSP cutoff wall onto the sea side to half that in Case-II (*see* Fig. 14). Consequently, the leachate leaked to the outside of the coastal landfill sites is reduced by the low hydraulic conductivity as well as the sparser arrangement of joint sections in the SPSP cutoff wall, thus, significantly improving the leachate-containment effect.

The H-jointed SPSP cutoff wall with H-H joints (Case-IV) most efficiently achieves low hydraulic conductivity with a sparser arrangement of joint sections. The leakage of leachates in Case-IV can be traced to the lower reaches of the cutoff wall, occurring via the clay deposit layer, which is one of the bottom cutoff barriers and is further away than other pathways such as leakage directly through the cutoff wall (*see* Fig. 16). Thus, the H-jointed SPSP cutoff wall with the H-H joint sufficiently contributes to the leachate-containment effect of vertical cutoff barrier at coastal landfill sites.

In this section, it was clarified that technologies that lower the hydraulic conductivities of joint sections in SPSP cutoff walls and also facilitate the use of sparser arrangements contribute significantly to increasing the environmental feasibilities of SPSP cutoff walls at landfill sites. Further, the extent of the environmental feasibility of H-jointed SPSP cutoff walls with the H-H joints among the present technical developments in SPSP

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cutoff walls was shown.

Conclusions

An evaluation method that can express the local leakage of leachate from joint sections in steel pipe sheet pile (SPSP) cutoff walls is discussed, in this study. In particular, the evaluation of environmental feasibility (containment of leachates containing toxic substances) considering a three-dimensional arrangement and hydraulic conductivity distribution of the joint sections in the SPSP cutoff wall is compared with an evaluation that generally uses the equivalent hydraulic conductivity.

Evaluations of the environmental feasibilities of the SPSP cutoff walls with joint sections that have a higher hydraulic conductivity than that of the steel pipe must take into account the local leakage of leachates containing toxic substances from the joint section; this was possible using the SP/JS-model. Due to the local leakage into the surroundings of coastal landfills from joint sections, contamination in excess of the environmental standard values was confirmed to occur earlier than that predicted by the UL-model, which is the current standard evaluation method.

It was clarified that technologies that lower the hydraulic conductivities of joint sections in SPSP cutoff walls and also facilitate the use of sparser arrangements contribute significantly to increasing the environmental feasibilities of SPSP cutoff walls at landfill sites. Further, the extent of the environmental feasibility of H-jointed SPSP cutoff walls with the H-H joints among the present technical developments in SPSP cutoff walls was shown.

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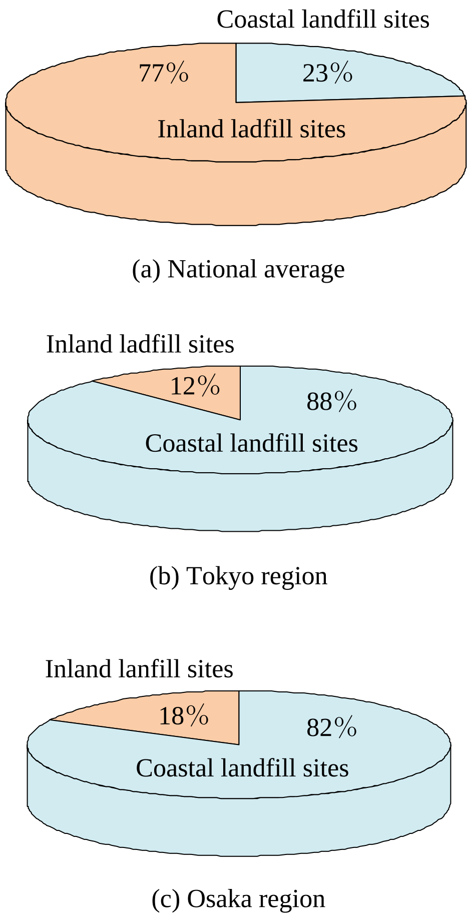

Fig. 1. Capacity comparison between inland and coastal landfill sites based on national statistics of 2003 announced at Ministry of the Environment, Japan

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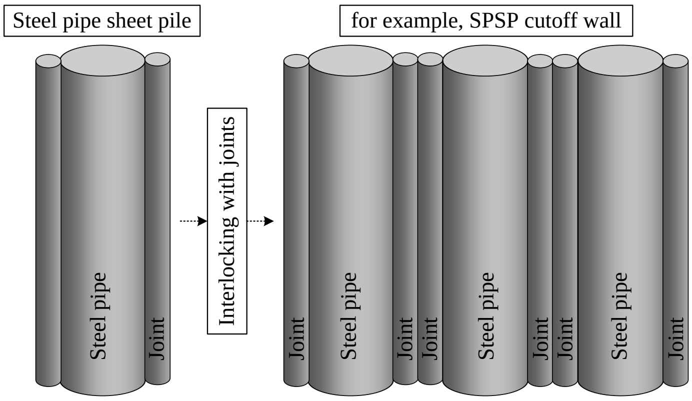
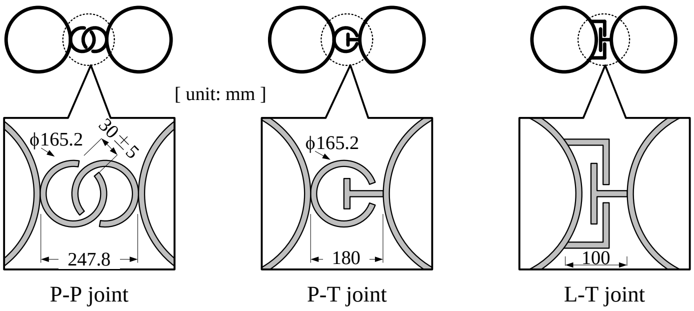


(a) Full view of steel pipe sheet piles (SPSPs)



(b) Geometries of P-P, P-T and L-T joint sections

Fig. 2. Schematic diagram of steel pipe sheet piles with joint sections

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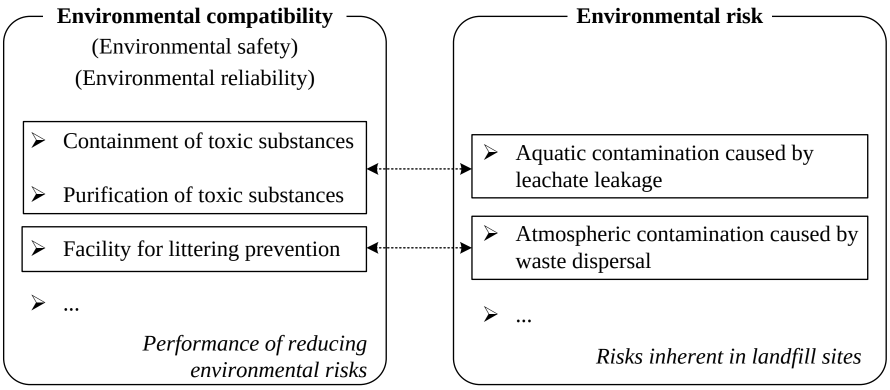

Fig. 3. Characterization of environmental feasibility on vertical and bottom cutoff barriers as well as overall landfill site

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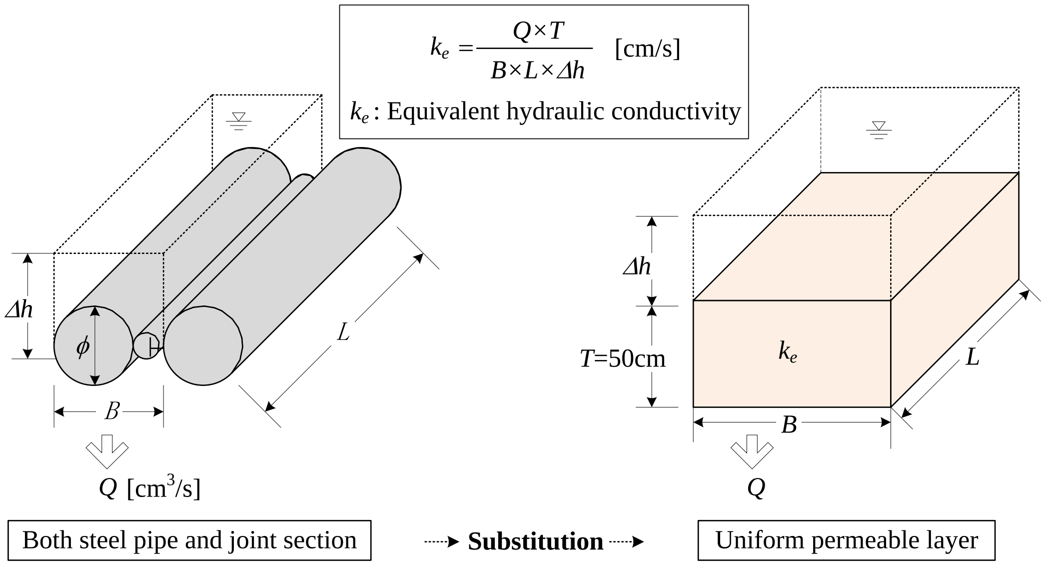

Fig. 4. Concept of equivalent hydraulic conductivity assuming that joint section and steel pipe are integrated

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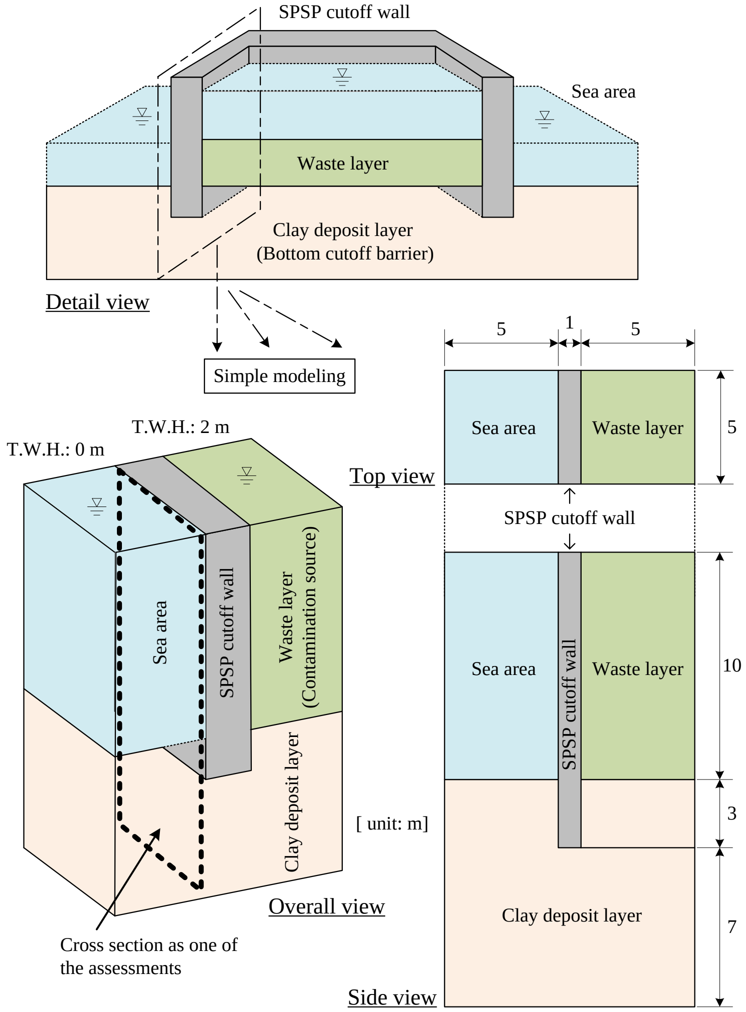

Fig. 5. Three-dimensional cross section of landfill site assumed as a basic case in the analysis

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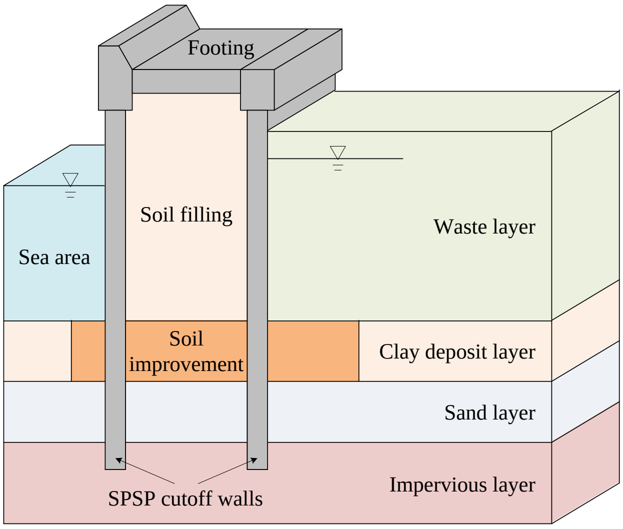

Fig. 6. Overview of vertical and bottom cutoff barriers generally constructing at coastal landfill sites

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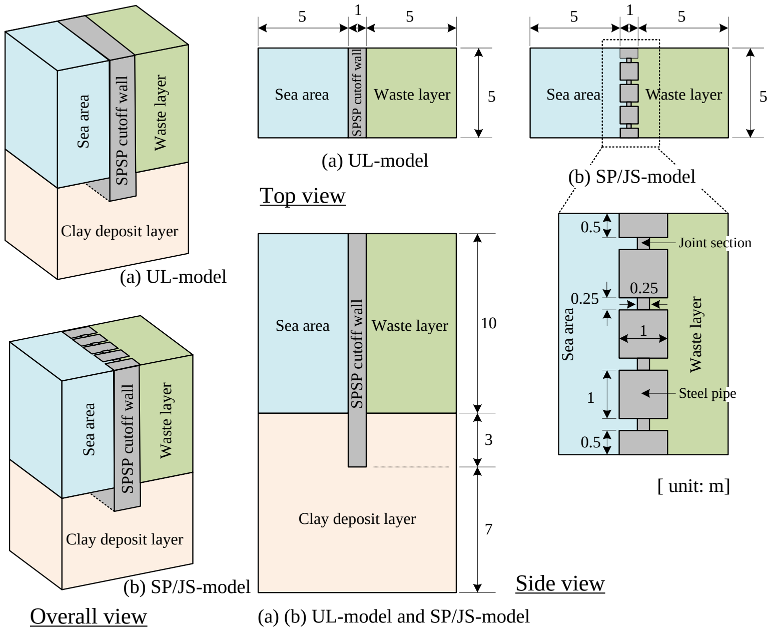

Fig. 7. General description of UL-model and SP/JS-model in the analysis

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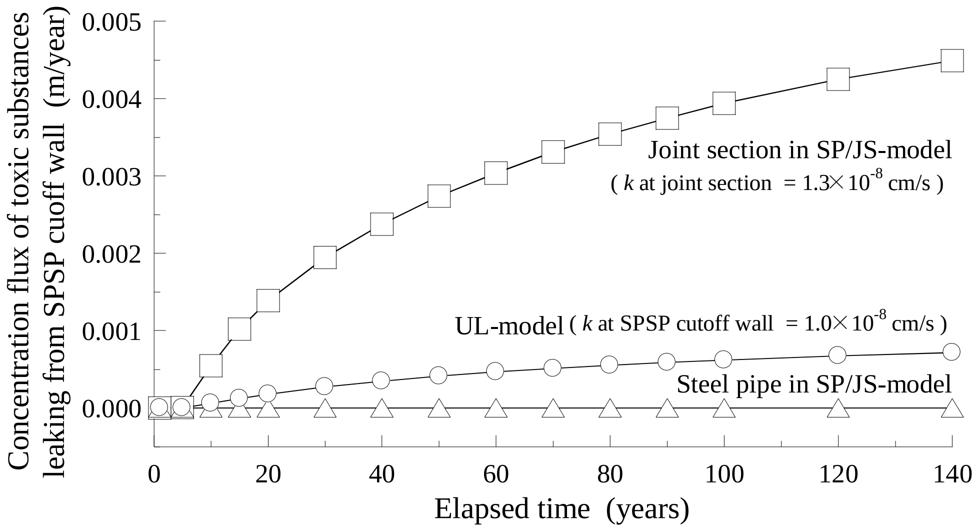

Fig. 8. Concentration flux of toxic substances leaking from SPSP cutoff wall on sea side with elapsed time for both models

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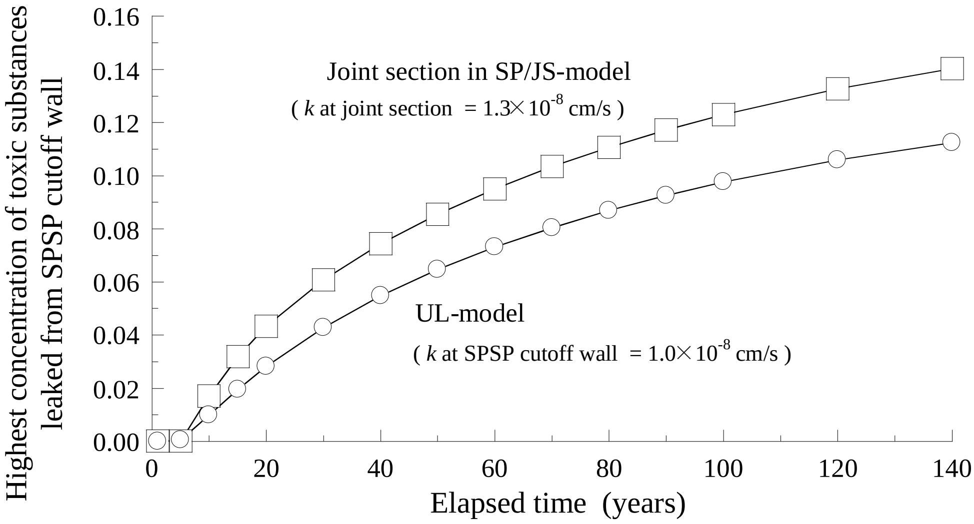

Fig. 9. Relationship between elapsed time and the highest concentration of toxic substances leaked from SPSP cutoff wall on sea side for both models

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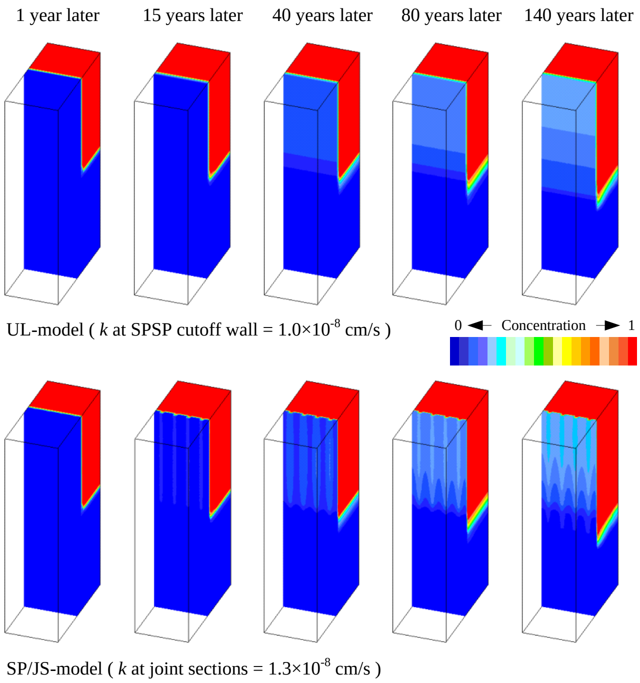

Fig. 10. Distribution of concentration of toxic substances leaking out from waste layer for both models

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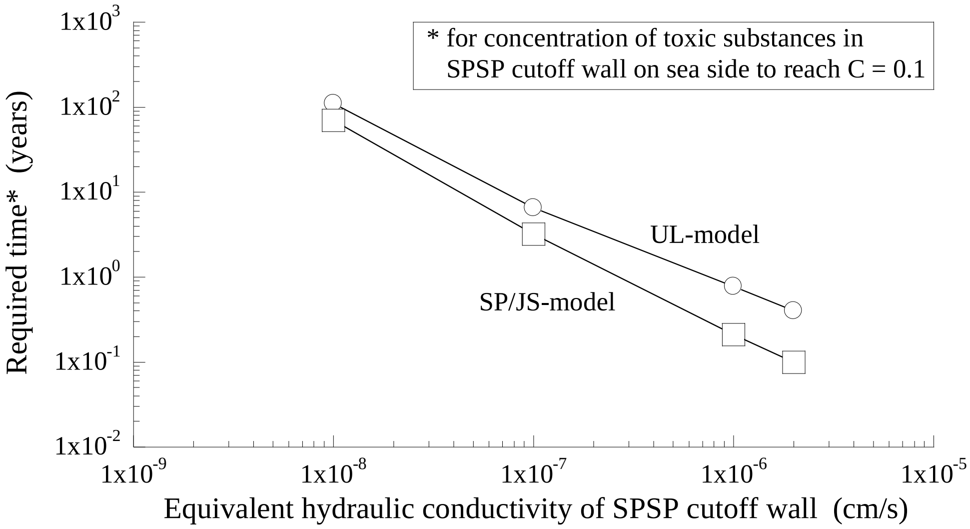

Fig. 11. Required time for concentration of toxic substances in SPSP cutoff wall on sea side to reach C = 0.1 with equivalent hydraulic conductivity of SPSP cutoff wall

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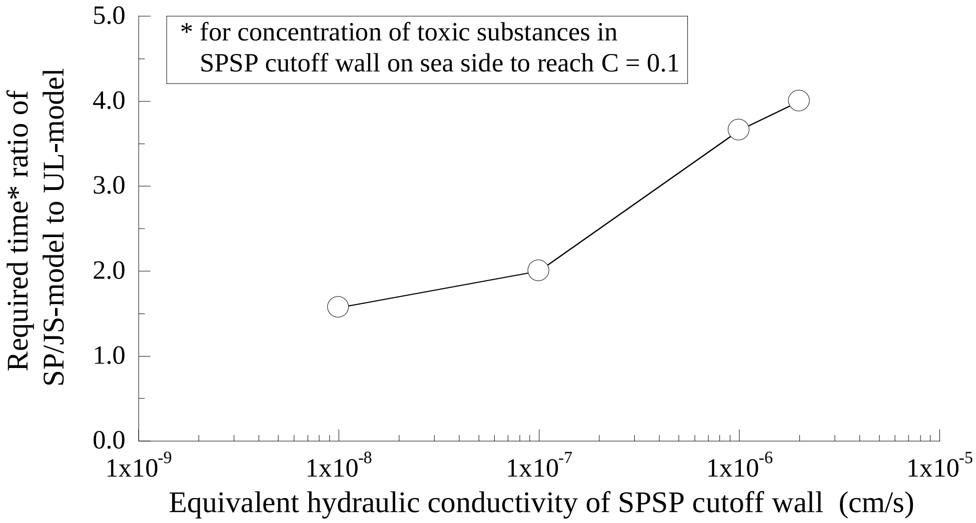

Fig. 12. Required time ratio of both models, for concentration of toxic substances in SPSP cutoff wall on sea side to reach C = 0.1, with equivalent hydraulic conductivity of SPSP cutoff wall

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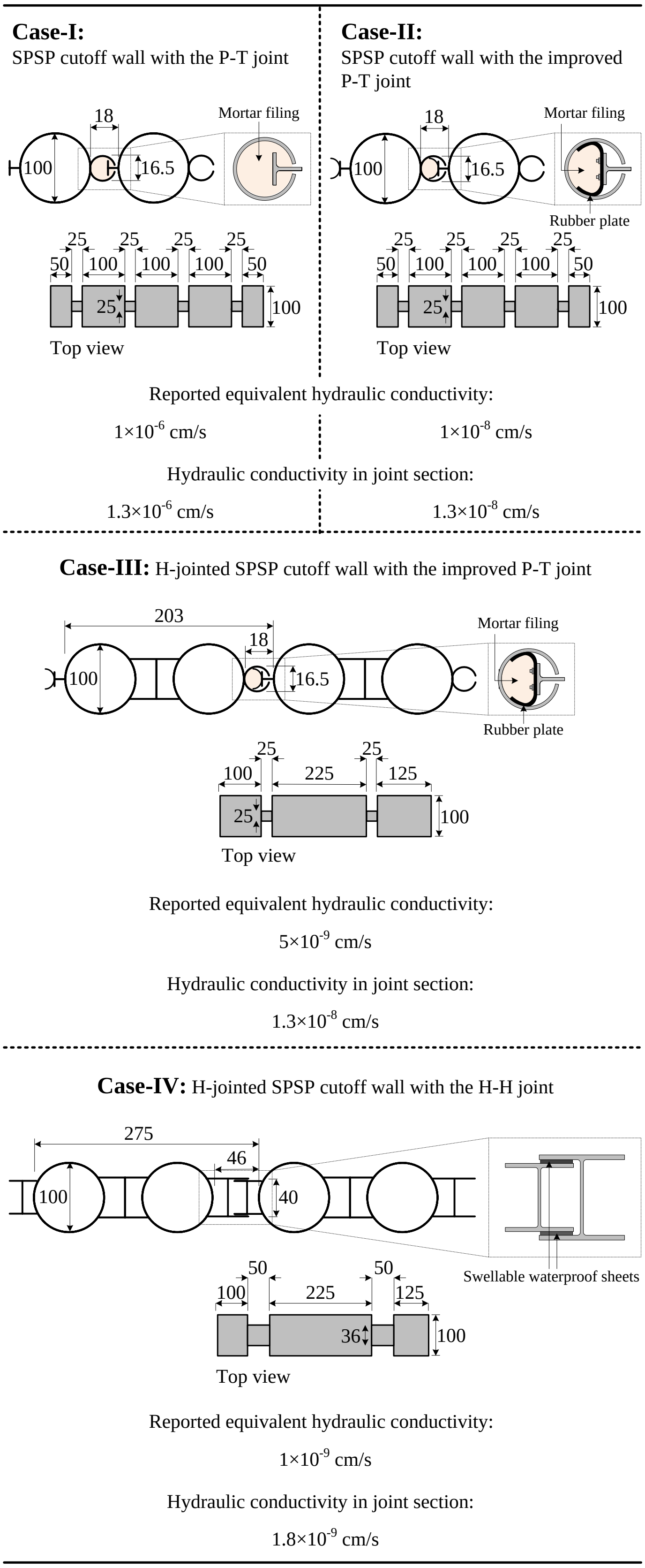

Fig. 13. Dimension and hydraulic conductivity of SPSP cutoff wall with each joint type and outline of SP/JS-model for Case-I to Case-IV

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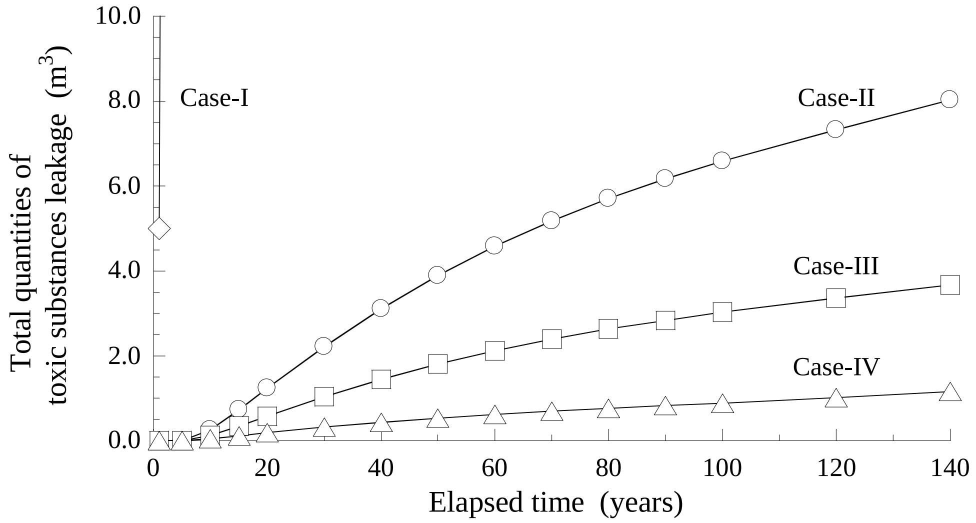

Fig. 14. Total quantities of toxic substances leaked from SPSP cutoff wall onto sea side with respect to the elapsed time for Case-I to Case-IV

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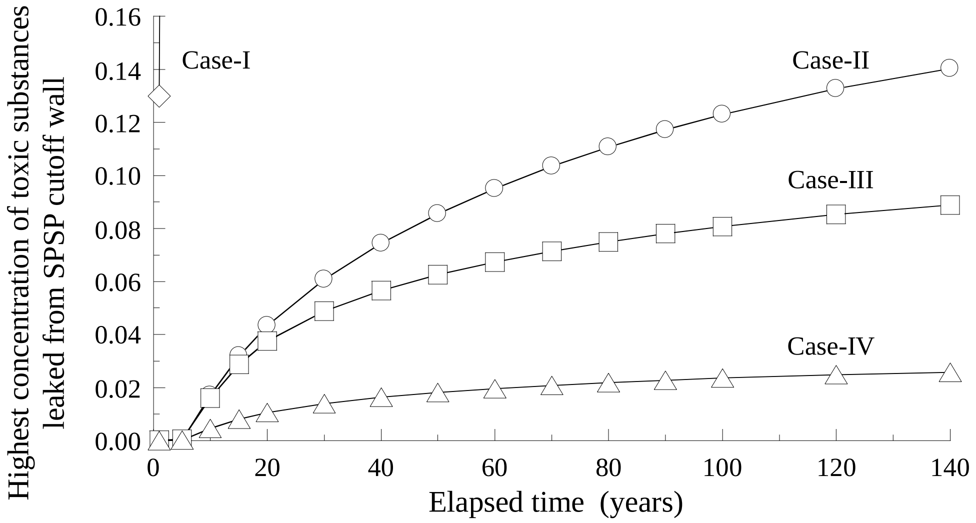

Fig. 15. Relationships between elapsed time and the highest concentration of toxic substances leaked from SPSP cutoff wall onto sea side for Case-I to Case-IV

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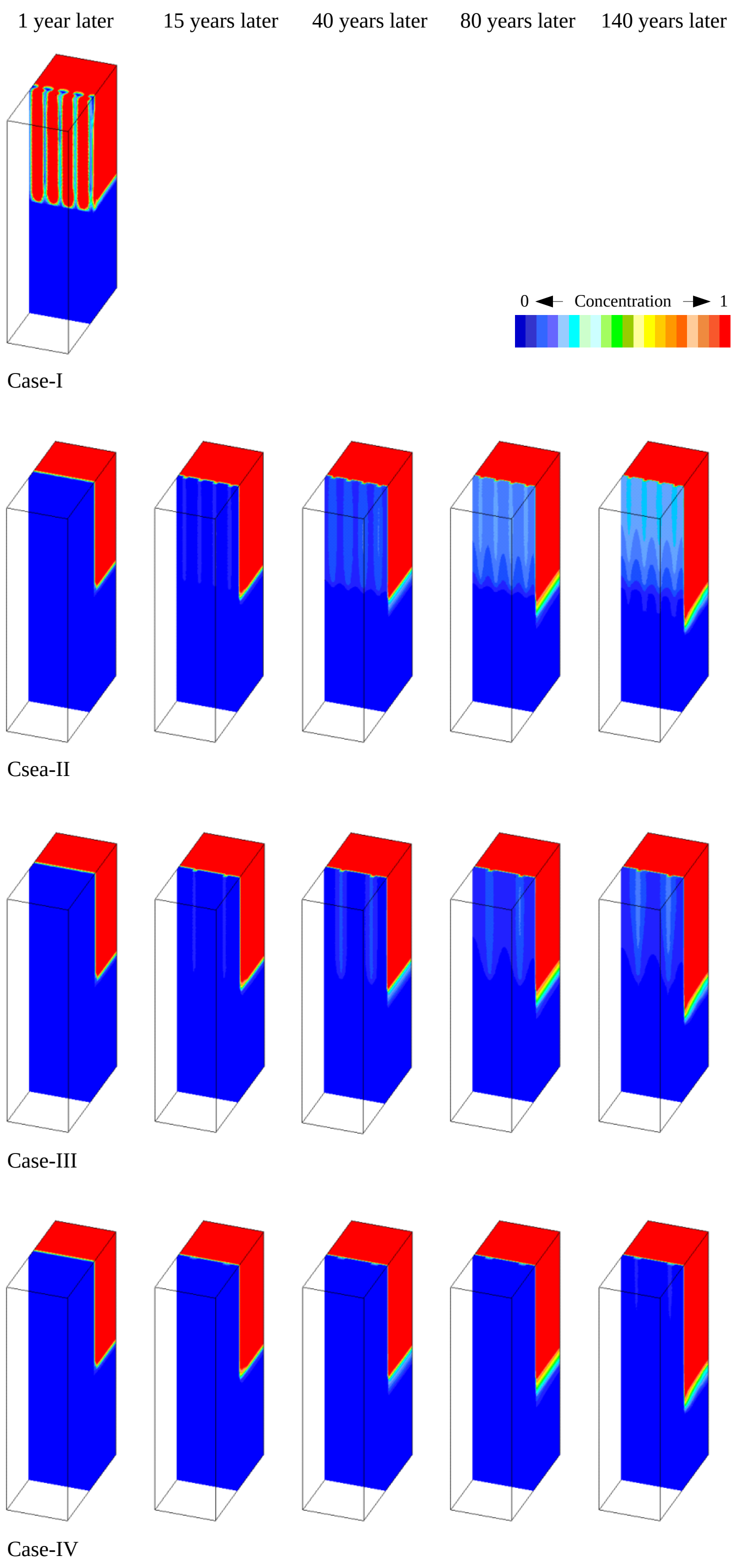

Fig. 16. Distribution of concentration of toxic substances leaking out from waste layer in Case-I to Case-IV

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Table 1. Seepage, advection and dispersion properties assigned to each composition layer in the analysis

			SPSP cutoff wall			Clay deposit layer	Waste layer	Sea area
			UL-model	SP/JS-model				
				Joint sec.	Steel pipe			
Horizontal hydraulic conductivity	k_H	cm/s	2.0×10^{-6}, 1.0×10^{-6}, 1.0×10^{-7}, 1.0×10^{-8},	2.5×10^{-6}, 1.3×10^{-6}, 1.3×10^{-7}, 1.3×10^{-8},	infinitesimal	7.0×10^{-7}	1.0×10^{-0}	1.0×10^{-0}
Vertical hydraulic conductivity	k_V	cm/s	2.0×10^{-6}, 1.0×10^{-6}, 1.0×10^{-7}, 1.0×10^{-8},	2.5×10^{-6}, 1.3×10^{-6}, 1.3×10^{-7}, 1.3×10^{-8},	infinitesimal	5.0×10^{-7}	1.0×10^{-0}	1.0×10^{-0}
Effective porosity	θ		0.1	0.1	0.1	0.65	1	1
Longitudinal dispersion	α_L	cm	10	10	infinitesimal	10	10	10
Transverse dispersion	α_T	cm	0.1	0.1	infinitesimal	1	1	1
Molecule diffusion coefficient	D_m	cm^2/s	1.0×10^{-5}	1.0×10^{-5}	infinitesimal	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}
Retardation factor	R_d		1	1	1	2	1	1

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Table 2. Environmental conservation standards associated with inland and coastal landfill sites

(a) For industrial waste reclaimed in landfill sites

Type of metals	Allowable limit
Cadmium and its compounds	0.1 mg/L or less
Lead and its compounds	0.1 mg/L or less
Hexavalent chromium compounds	0.5 mg/L or less
Mercury and its compounds	0.005 mg/L or less

(b) For water pollution of groundwater

Type of metals	Allowable limit
Cadmium its compounds	0.01 mg/L or less
Lead and its compounds	0.01 mg/L or less
Hexavalent chromium compounds	0.05 mg/L or less
Mercury and its compounds	0.0005 mg/L or less

(c) For soil contamination

Type of metals	Allowable limit
Cadmium its compounds	0.01 mg/L or less
Lead and its compounds	0.01 mg/L or less
Hexavalent chromium compounds	0.05 mg/L or less
Mercury and its compounds	0.0005 mg/L or less